LOW ENERGY GAMMA RAY IMAGER ON MINISAT- 01

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ABSTRACT

The Low Energy Gamma Ray Imager (LEGRI) is one of two astronomical instruments on the MINISAT-01 mission and is devoted to exploring the hard X-ray and low gamma-ray emission of the celestial bodies. MINISAT-01 launch is due for December 1996 by a Pegasus launcher in the Canary Islands area.

A coded mask coupled to a 100 pixel detector plane formed by 80 HgI2 and 20 CdZnTe solid state detectors provide good imaging capabilities with a 20′ point source location capability at 20-100 KeV spectral region. Around 40 objects are expected to be monitored during the 2 years of MINISAT 01 nominal life time. The Galactic Center region, black hole candidates, neutron stars in binary systems and hard X-ray emitters are among the LEGRI targets.

Notwithstanding of LEGRI performance as an operational astronomical instrument, the LEGRI main goal is to demostrate the technological feasibility of future gamma ray imagers based on solid state detector technology and coded mask techniques. LEGRI can be seen as a precursor of the IBIS imager on the ESA INTEGRAL mission.

LEGRI has been developed by a consortium formed by the University of Valencia, INTA and CIEMAT in Spain and RAL, University of Birmingham and University of Southampton in the UK. In this paper we present a review of the LEGRI technologies, main subsystems, operations plan and some details about the LEGRI collaboration and management system.

1.- DEFINITION. SCIENTIFIC AND TECHNICAL OBJETIVES

1.1.- LEGRI Philosophy

Since its conception in March 1993, LEGRI has been designed as a demonstration of technology payload for future generations of gamma-ray telescopes, with imaging capability based on solid-state detectors. LEGRI is an astronomical instrument characterised by its simplicity, low-mass and high efficiency, able to produce images in the hard X-ray / soft gamma-ray domain whose purpose is to explore and demonstrate new technologies that will be used by the successors of SIGMA and GRO, such as INTEGRAL.

The main constituents of LEGRI are two new technologies: a coded system acting over a pixellated detector plane, and a matrix of solid state detectors of HgI2 and CdZnTe.

Coding of the signal is performed by a coded mask located 54 cm above the detector plane. The mask pattern is a 5x5 MURA placed in a mosaic of 14 x 14 pixels, each of size 24 x 24 mm, made out of tungsten pieces 1mm thick. A tantalum collimator is situated between the coded mask and the detector plane, in order to restrict the FOV to match that of the mask. With the coded system composed by the coded mask and the collimator, LEGRI achieves an angular resolution of 2.2° and a point source location capability (PSLC) of 20 arcmin within a fully coded field of view (FCFOV) of 11°. A coded system similar to LEGRI has been used in the Franco-Soviet SIGMA mission. More details about the mask coding pattern and deconvolution algorithms can be found in Ballesteros et al., 1996 and Ballesteros 1996.

The second novel technology in LEGRI is the use of solid-state crystals as detector elements. Initially, 100 HgI2 detectors of size 1cm2 x 0.5 mm thick were selected, based on a crystal-growth technology under development by the Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (CIEMAT). This type of detectors provides clear advantages over currently used detectors based on scintillators coupled to PMT′s or photodiodes. They are primary detectors working by collecting the electrons and holes on the electrodes without any intermediate energy transfer process. The solid state detectors give reductions of one or two orders of magnitude in mass, volume, complexity and power consumption with respect to scintillators. For space applications the HgI2 detectors also present clear advantages over other solid state detectors like the Germanium, as they work at room temperature avoiding the use of complex cooling systems.

Finally, and without describing the LEGRI detectors in too much more detail, it is worth noting the well-demonstrated survival capacity of the HgI2 detectors under doses of 10*14 neutrons/cm2, or 10*12 protons/cm2 at 10 MeV without suffering appreciable degradation, (Perez, 1990). This survival capacity is especially relevant to long-duration space missions that repeatedly pass through regions of high density energetic particles.

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The initial configuration of the LEGRI detector plane formed by 100 HgI2 detectors was changed in 1995, by the substitution of 20 HgI2 detectors for 20 CdZnTe detectors of 1 cm2 and 1mm thickness developed in collaboration with the CALTECH high energy group. This change increased the LEGRI potential as a demonstrator of new technologies, since now it will be possible to compare the performance of both kinds of detectors working simultaneously side-by-side in the same detector plane, using the same FEE and working under the same background fluxes. More details about the HgI2 LEGRI detector technology can be found in Peréz et al., 1996.

The main features of LEGRI in its flight configuration, after the inclusion in 1995 of the CdZnTe detectors, can be seen in Table 1. The estimated LEGRI sensitivity can be found in Porras et al., 1996, with a description of the background estimation used.

ENERGY RANGE	20-100 KeV
DETECTORS	80 HgI2 + 20 CdZnTe
CONTINUUM SENSITIVITY	8 mCrab at 30 KeV in 10**5 sec (3 sigma)
SPECTRAL RESOLUTION	40% at 30 KeV
ANGULAR RESOLUTION	2.2 degrees
POINT LOCATION CAPABILITY	20 arcmin
FIELD OF VIEW (FCFOV)	11 degrees

Table 1. LEGRI Key Performance Parameters

1.2 LEGRI Science

Complementing the technological objectives described above, during the 2-year operation lifetime of MINISAT-01, the LEGRI team intends to monitor a sample of hard X and soft gamma-ray emitters in the energy range between 20 – 100 KeV. This energy band is of particular astrophysical interest because unique astrophysical information regarding nuclear excitation processes, radioactivity, cyclotron emission, etc., is contained within this region of the electromagnetic spectrum. In particular, in this region, the emission process generated by bound electronic transitions in atom ends, and nuclear excitation processes start to dominate. Electronic transitions in the atoms in the outermost layers of the stellar atmospheres end their contribution to the observed spectra because the nuclei are almost stripped due to the high degree of ionisation. The observed spectra remain clear of these contributions, and only the nuclear excitation processes in their diverse forms, together with ionised plasma emissions, are present.

For many high-energy cosmic emitters, it is crucial to collect data in these spectral regions, in order to be able to model in detail the different contributions present in the observed spectra. It is particularly important to be able to observe the ends of the X-ray tails, to determine their possible extension into the gamma-ray region which many sources indicate. Multimodel components may be necessary to fit the observed spectra. For highly variable objects, the investigation of the variation on different temporal scales could provide valuable information about the dimensions of the emitting regions and their internal structures.

Despite the high astrophysical interest in this spectral region, there is significant lack of data mainly due to instrumental limitations. The X-ray detectors used up till now drop in their efficiencies typically around 50 KeV, while gamma-ray detectors based on scintillators are usually limited to energies above 30 KeV. With LEGRI we intend to cover this region by using the same kind of detector technology, at least for the brightest emitters, having continuum fluxes within the LEGRI sensitivity range.

The poor energy resolution of LEGRI prevents us performing line observations, reducing the spectral capability to relatively wide spectral bands (one o more tens of KeV, depending on the energy). Although some individual HgI2 detectors tested with laboratory electronics present very promising spectral resolution (8% at 30 KeV) the energy resolution average for the 10x10 matrix is quite worse (14%). Their energy resolution drops by some 30-40% when the detectors are coupled to the flight electronics. The LEGRI FEE electronics is a modification of the FEE developed for the INTEGRAL Imager CsI scintillators and consequently it is not the most suitable for solid state detectors. With these limitations, LEGRI will work more like a photometer with two or three bands than a true low resolution spectrometer.

The selection of LEGRI targets and observing times for each field is the responsibility of the LEGRI Science Team, and it is constrained by the instrument sensitivity, field-of-view, and operation characteristics of the MINISAT-01 mission. Full details about the Observation Programme and SOC tasks can be found in Robert et al., 1996.

Finally, we would like to point out that the LEGRI main detector is complemented by a Star-Sensor that will allow us to move from the 3° error on the pointing provided by MINISAT-01, to an error of few arcmin on the pointing reconstruction. In this way, we expect to exploit the full LEGRI capabilities acting as an imager that otherwise is compromised by the very poor pointing of the MINISAT-01 guidance system.

2.- HARDWARE DESCRIPTION

The LEGRI system is formed by seven subsystems: Detector Unit, Coded Mask, Data Processing & Power Supply Unit, High Voltage Unit, Star Sensor and Science Operation Center. LEGRI on MINISAT-01 can be seen in Figure 1.

Detector Unit (DU): The LEGRI detector unit is a rectangular box of 149x281x 208.5mm formed by the following elements:

A position sensitive gamma-ray detector consisting on an array of 80 HgI2 detectors of 6x6 mm2 , each 0.5mm thick, and 20 CdZnTe detectors of 10x10 mm2 and 1mm thickness arranged on a 12x12 mm2 spaced grid. Two palladium electrodes are deposited on both crystal sides of the HgI2 detectors which then covered with silicone and paralyne to prevent outgassing. The CdZnTe's are encapsulated with a silicone film. The detectors are located on a CFRP arrays of 10 detectors each one that provides the required stiffness to the detector plane. The total useful collecting area is 30 cm2 for the HgI2 and 20 cm2 for the CdZnTe.

The associated Front End Electronics (FEE) is based on a 16 channel low-noise preamplifier and shaping-amplifier chip developed at RAL. This chip require a digital drive circuit and ADC (DFEE), developed using gate array type technology and commercial ADC. We have used 10 AFEE cards, each of them connected to an array of 10 detectors, using only 10 channels of each integrated circuit. The two 10 CdZnTe detector arrays are located on the right and left sides of the detector plane. The DFEE card is placed at the back of the box, isolated by an electrical screen to avoid interferences to the AFEE.

A mechanical collimator made of tantalum 12x12 x58.5 mm size and 0.2mm thickness is located over the detector plane to restrict the field of view to the fully coded field of view defined by the mask.

The internal structure of the Detector Unit consists of some aluminium frames, which are the base on which the other elements inside the box are fixed: collimator, detector plane and FEE. The sides and rear of the box are surrounded by a four layer graded passive shield formed by an outher Pb layer, then Ta followed by Sn and finally a later of Fe with thickness of 2, 0.25, 0.5 and 1mm respectively. More details about the passive shielding and background estimations can be seen in Porras et al. 1996 and Robert et al. 1996.

Coded Mask (CM): The mask located 540 mm from the detector plane and parallel to it is formed by an array of 14x14 tungsten elements, each of size 24x24mm2 and 1mm thickness enbebed in a carbon fibre honeycomb structure. The gamma-ray transparency of the pixels is less than 10% at 160 KeV. The honeycomb is located inside an aluminium frame attached to two aluminium structures that provide the mechanical support interfaces with the MINISAT-01 Payload Module. Mask dimensions are 350x353x15 mm.

Data Processing and Power Supply Units (DPU): The data processing and power supplies are housed within a single box. It is based on a unit developed for the JET-X instrument on the SPECTRUM-X mission. The DPU is based on a Harris 80C86 microprocessor, with 16 Kbyte RAM, together with interrupt and DMA controllers. The microprocessor controls the interfaces with the MINISAT OBDH and the rest of LEGRI units. The Power supplies are based on Interpoint DC - DC converter modules. The converters which provide +5V and ± 12V secondary power to the HV Supply Unit and detectors are left switched on permanently. Other converters providing secondary power are switched on and off by high-level commands in order to minimise LEGRI power consumption in standby. More details about LEGRI DPU&PSU can be found in Eyles et al.1996.

High Voltage Supply Unit (HV): The HV power supply unit is based on a unit developed for the ESA SOHO mission. A modified version was developed for LEGRI, built to the same standards as the SOHO unit.

Star Sensor (SS): Because the limited pointing reconstruction accuracy capabilities of the MINISAT-01 mission (3 degree) a Star Sensor has been included as an element of the LEGRI instrument. The SS will be used to determine the attitude of the satellite by measuring the relative positions in its field of view of a number of reference stars. The precession with which the position of the stars has to be determined should be of the same order than the Point Source Location Capability of LEGRI, namely 20 arc sec.

Science Operation Center (SOC): The LEGRI SOC is located at the University of Valencia equipped with twin SUN 20 biprocessor workstations and a link to the MINISAT-01 Centro de Operaciones Cientificas (COC) located at Villafranca del Castillo (Madrid). A summary of the LEGRI mass and power budgets can be seen in Table 2.

Detector Unit	11,2 Kg
Mask Assembly	2.5 Kg
Data Processing & Power Supply Units	5.5 Kg
High Voltage Supply Unit	0.4 Kg
Star Sensor	2.8 Kg
Total Mass	22.4 Kg
Total Power	14.3 w

Table 2. Mass & Power Budgets

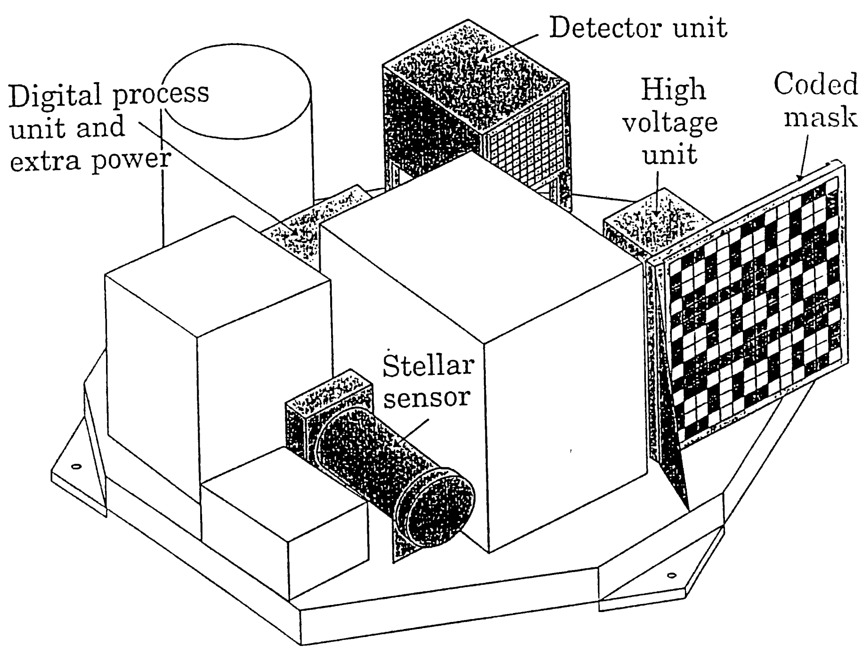

Fig 1. LEGRI on MINISAT-01

3. LEGRI COLLABORATION AND OPERATIONS

LEGRI has been developed jointly through a Spanish-British collaboration formed by the University of Valencia, Instituto Nacional de Tecnicas Aeroespacilaes (INTA) and the Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (CIEMAT) in Spain, the Rutherford Appleton Laboratory (RAL) and the Universities of Birmingham and Southampton in the United Kingdom.

From the beginning of the LEGRI collaboration, one of the main goals was to simplify the project management system by means of assigning very well-defined work packages, at the subsystem level, to each institution. In this way we avoided the duplication of work within geographically separate groups, and focused each group on the development of their LEGRI subsystems within their area of expertise. Each subsystem was placed under the full responsibility of a given group, each group being solely responsible for the development and flight qualification of their hardware component according to the general model philosophy based on the development of a STM, EQM and FM models. By following this plan, the LEGRI subsystems were qualified either in the UK or at INTA, thus minimising their costs. Ground calibrations were carried out in two sessions, in January 1996 at Birmingham and during final integration and acceptance tests at INTA in September 1996.

The Workpackage breakdown within the collaboration was as follows:

INTA: Central Management, Qualification and Test.
CIEMAT: HgI2 detectors.
University of Valencia: Detector Unit, Coded Mask and Science Operation Center.
RAL: FEE, High Voltage Unit and Star Sensor.
University of Birmingham: Data Processing and Power Supply Units, UK System Engineering, CdZnTe detectors in collaboration with CALTECH.
University of Southampton: Electrical Ground Support Equipment.

The top level LEGRI management system can be seen in Figure 2.

With this management system we have been able to develop LEGRI and deliver it fully qualified for flight in a short timescale of only 35 months from project inception to INTA delivery (March 1993 to January 1996), and with substantially reduced costs with respect to the norm for these types of space projects. In fact LEGRI was largely developed using internal funds from institution within the collaboration.

The implementation of the scientific operations of LEGRI is a responsibility of the SOC located at the University of Valencia, which at the same time acts as the single contact-point between the LEGRI collaboration and the INTA Centro de Operaciones Cientificas (COC). The SOC will implement the telecommand scripts and will perform the quick-look of the images. Deconvolution software has been developed by the SOC and is now fully operational on standard Sun workstations. The scientific analysis of the data will be performed by a few working groups formed by investigators from the different institutions within the LEGRI collaboration. More details about the SOC tasks and hardware configuration can be found in Robert et al. 1996.

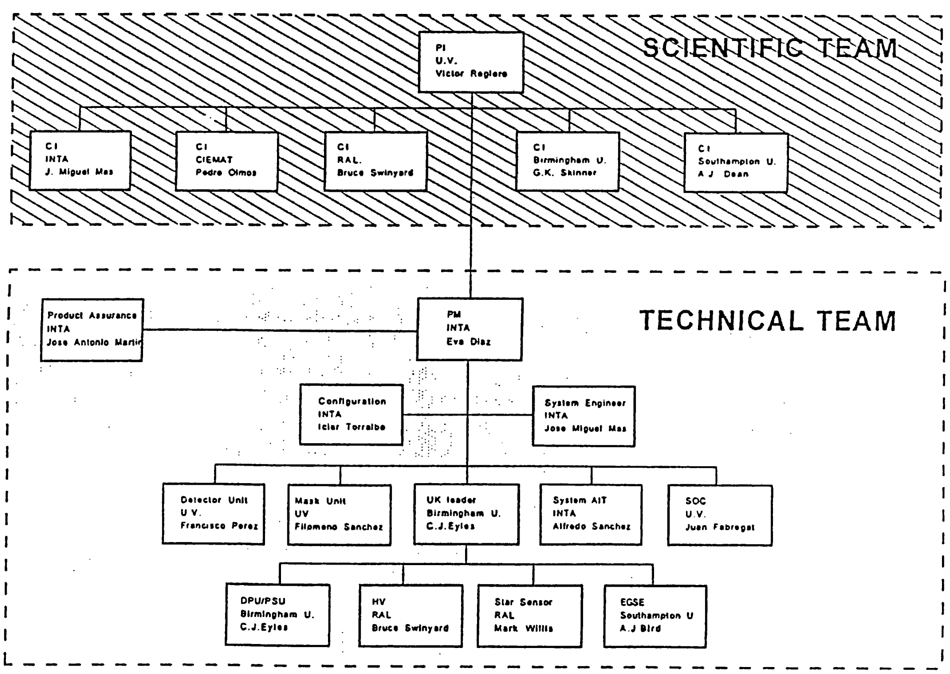

Figure 2. LEGRI Organisation Breakdown Structure

4.- CONCLUSSIONS

The LEGRI project can be seen as a good example of a payload development that exploits to the maximum the capabilities offered by small missions or mini-satellites such as MINSAT-01. There are four invaluable elements of LEGRI when regarded as a payload for a small mission: technological innovation, simplicity, low cost, short development time.

LEGRI contains elements of high technological innovation and scientific interest that it is necessary to test in space before their widespread use in other larger missions such as INTEGRAL. It is a simple payload in which we have used existing and fully developed hardware (HV, DPU) as well as components under development for other missions (as with the FEE). It is a low-cost payload, as much for the use of off-the-shelf components, as by the implementation of a simple and decentralised management system. This approach enabled the project to be funded with minimal support from national funding agencies. Finally, the development of LEGRI was carried out very quickly (in less than 3 years), in comparison with typical timescales (10 years) for space-borne instrumentation.

Apart from the technological benefits, LEGRI will produce a valuable quantity of scientific data by means of a simple observational programme centred on very few and concrete observational goals.

Finally, we would like to point out that the consolidation of personnel and expertise within the Spanish teams that has resulted from the LEGRI development activities will be very useful for future projects and participation in larger multinational missions. In particular, the immediate benefit has been the availability of expertise to work on the Spanish participation within the INTEGRAL project. LEGRI is the first astronomical instrument developed under Spanish leadership just as MINISAT-01 is the first in the field of mini-satellites.

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